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ROUTING AND SCHEDULING FOR THE TRANSPORTATION OF THE DISABLED PERSONS : TEST PROBLEMS AND EVALUATION OF RESULTS

by

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17. Abstract

The main objective of the project were to develop an algorithm and computer programs for the construction of vehicle routes and schedules. A secondary objective was the coding of test problems which could be used to validate the software developed or which could be used in other studies concerning the transportation of the handicapped. The algorithm and computer programs were successively improved with the help of tests carried out on the coded data. In the system developed, special attention was devote to the evaluation of the distance between stops to be visited. This led us to the use of the Area Master Files, a set if files containing various items of geographical data. In the route and schedule construction algorithm, quality of service and vehicle productivity are the two criteria considered. Test results demonstrate the advantages of the computer system over manual methods.

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17. Résumé

Les principaux objectifs du projet étaient de développer un algorithme et des programmes informatiques pour confectionner des routes et des horaires de véhicules. Un objectif secondaire était la codification de problèmes tests pouvant servir à valider le logiciel développé et à d'autres études touchant le domaine du transport adapté. L'algorithme et les programmes informatiques furent améliorés successivement, à l'aide des tests effectués avec les données codifiées. Dans le système développé, un soin particulier est apporté à l'évaluation des distances entre les arrêts à visiter. Le dernier point nous a amenés à utiliser des AMF (Area Master Files), un ensemble de fichiers contenant diverses données géographiques. Dans l'algorithme de confection des routes et d'horaires, la qualité du service et la productivité des véhicules sont les critères considérés. Les résultats obtenus avec les tests effectués démontrent les avantages du système informatique comparativement à la méthode manuelle.

18. Mots-clés	19. Diffusion
algorithme, horaire, personnes handicapées, route, transport adapté	Nombre limité d'exemplaires disponibles au C.D.T.

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SUMMARY

To validate the computer programs developed for this project, we coded data for one day of operations in the cities of Montréal, Toronto and Sherbrooke. For each city, all transportation requests were coded. In addition, for Toronto and Montréal, we also coded the routes planned by the transporter to satisfy the demand. The quality of service provided to users and vehicle productivity are the criteria considered in evaluating a vehicule route on schedule.

TABLE OF CONTENTS

1. INTRODUCTION 1

2. EVALUATION CRITERIA FOR ROUTES AND SCHEDULES 3

3. INFORMATION CONSIDERED IN THE CONSTRUCTION OF ROUTES AN SCHEDULES 5

4. TESTS DATA FROM THE TORONTO WHEEL-TRANS SERVICE. 7

5. TESTS WITH DATA FROM THE MONTREAL URBAN COMMUNITY TRANSIT COMMISSION 27

6. TESTS WITH DATA FROM THE SHERBROOKE MUNICIPAL TRANSIT CORPORATION. 43

7. CONCLUSION 53

REFERENCES 55

1. INTRODUCTION

This is the third report on a research project being carried out by the Centre de recherche sur les transports with the support of a joint grant from the Roads and Transportation Association of Canada (RTAC) and the Transportation Development Centre (TDC) of Transport Canada. The project involved the development of software for route and schedule construction for the transportation of the handicapped. This software does not carry out managements tasks such as reservations and cancellations, etc. The reader will find a description of the software in the report "Development of vehicle routes and schedules for the transportation of the handicapped : analyst's manual and computer programs" [2]. For the specific task of route and schedule generation, a technical description of the algorithm used can be found in the document "Development of vehicle routes and schedules for the transportation of the handicapped : the algorithm" [2].

This report contains tests on a typical day for the cities of Montréal, Toronto and Sherbrooke, as well as an evaluation of the routes actually executed in Montréal and Toronto. The purpose of these tests was to adapt the software to different contexts and to validate it. The comparison of the results obtained with the actual routes used is somewhat biased for the following reasons :

- The tests did not take into account operating rules such as reservations periods and user call-back.
- The tests did not take into account certain aspects of reality, such as cancellations and "no shows".
- In addition, the present quality of the routes in operation in the cities studied has a historical explanation. The routes may have deteriorated after successive modifications.

The tests allowed us to validate the software and to construct a bank of test problems. The software and the Toronto test problem are being used in a study, begun at the Centre de recherche sur les transports in 1984, in which the impact of various operating rules on the construction and quality of routes is being evaluated [6].

2. EVALUATION CRITERIA FOR ROUTES AND SCHEDULES

In the evaluation of a route and schedule for a vehicle, two aspects must be considered : the quality of the service provided to passengers and the productivity of the route. For each of these items, we define a set of statistics.

2.1 Quality of service

To evaluate the quality of service provided for a transportation request, two criteria must be considered : the delay with respect to the desired service time, and excess travel time.

The user specifies a type of transport and a desired service time; for example, he or she may specify a desired arrival time of 9h00 or a desired departure time of 17h00. In the case of a desired arrival time, the request is respected if user is delivered at his or her destination before the desired time and the delay corresponds to the difference between actual arrival time and desired arrival time. If the user is delivered after the desired arrival time, this delay is negative expressing the fact that the desired arrival time was not respected. In the case of a desired departure time, the request is respected if the user is picked up after the desired time where the service delay corresponds to the difference between the actual pick-up time and the desired time. If the user is picked up before his or her desired departure time, the delay is negative to express the fact that the desired departure time is not respected.

In this type of transportation, users must often travel with other passengers. Each request is not necessarily served directly. In order to serve other requests, a passenger may have to spend extra travel time in the vehicle. This excess travel time is evaluated by substracting the time to go directly from the origin to the destination from the total time the user spends in the vehicle. The total inconvenience to the client can be considered to be the sum of inconvenience due to excess travelling and inconvenience due to service delays.

For each route, we provide the nine following values :

a) the number of requests served by the vehicle;
b) the number of requests for which the service time is not respected;
c) the average service time violation;
d) the maximum service time violation;
e) the number of requests for which the service time is respected;
f) the average deviation from desired service time;
g) the maximum deviation from desired service time;
h) the average excess travel time;
i) the maximum excess travel time.

2.2 Route productivity

To measure route productivity, we provide the following basic statistics for each route :

a) the total travel time for the vehicle;
b) the total travel time without passengers;
c) the total vehicle waiting time;
d) the total handling time on the route;
e) the number of requests served by the vehicle;
f) the number of passengers served by the vehicle.

We define three productivity rates : the driver productivity rate (DPR), vehicle productivity rate (VPR) and passenger productivity rate (PPR). The rates are defined as follows :

$$DPR = \frac{\text{number of passengers transported}}{\text{paid time of driver}}$$

$$VPR = \frac{\text{number of passengers transported}}{\text{travel time of vehicle + handling time}}$$

$$PPR = \frac{\text{number of passengers transported}}{\text{travel time of vehicle with passengers + handling time}}$$

DPR represents the number of passengers transported per paid hour of the driver. The vehicle may sometimes be waiting, so VPR measures the number of passengers transported per hour of vehicle movement including empty running. To remove these unproductive trips, we define PPR, the number of passengers transported per hour of productive vehicle travel time. For a given route, the following relationship holds :

$$DPR < VPR < PPR$$

In the type of routes we produce, pick-ups and deliveries of clients may overlap. Requests are not necessarily served directly. It is interesting to compare this type of route with a route in which all requests are served directly by taxi. In this case, empty running times would not be taken into account and all clients would receive a good quality of service. With the first type of route, we hope to reduce vehicle travel by fitting together requests which have an origin or destination close to one another. To measure this difference in distance travelled with one type of route versus the other, we define for each route the taxi-vehicle ratio (TVR) :

$$TVR = \frac{\text{sum of direct travel times from origin to destination + handling time}}{\text{actual vehicle travel time with passengers + handling time}}$$

If, for a given route, TVR is greater than 1, a gain in distance has been achieved by overlapping the requests.

3. INFORMATION CONSIDERED IN THE CONSTRUCTION OF ROUTES AND SCHEDULES

In the present section, we briefly describe the information used in the construction of routes and schedules. For further details, the reader should consult the document describing the algorithm [1], and that describing the computer programs [2]. In addition, we indicate how the information on routes carried out by the cities had to be completed to produce an evaluation of these routes.

For each city, we distinguish two categories of requests : regular and occasional. Requests arriving on the same day as service is required are not considered. Using the original transportation request forms, we obtain the following information on each request :

- request identifier,
- name of group or client,
- request category (regular or occasional),
- origin address,
- destination address,
- type of service required (arrival or departure),
- number of passengers, number of wheelchairs, number of ambulatory persons, number of accompanying persons,
- desired service time.

The desired service time corresponds to the service time originally requested by the user, which may be different from the time the user actually obtained in the routes and schedules in operation. This may be due to a change requested by the user, on the impossibility of satisfying the request. For certain requests, the desired service time is flexible allowing for some negotiation between transporter and user. We have no information on the days and times at which occasional requests come in. We therefore handle all these requests at the same time e.g. in the evening preceding the day of service.

The information on the requests had to be completed by adding a handling time at the origin and destination of each one.

A set of driver days is requires for the construction of routes and schedules. For each working day, we code the following information :

- the number of pieces of work making up the day,
  and for each piece of work :
  - . the vehicle departure address,
  - . the vehicle arrival address,
  - . departure time for the piece of work,
  - . finishing time for the piece of work,
  - . vehicle capacity for wheelchairs,
  - . vehicle capacity for ambulatory passengers.

To estimate the travel time between stops (the origins or destinations of requests), we use a graph representing the road network. In this graph, an arc represents a street segment and a node represents an intersection. With each arc is associated a distance corresponding to the length of the road segment represented. Each stop to be visited is located at the nearest node in the graph. Thus, the distance between two stops is found by finding the shortest path between the two nodes associated with the two stops. The travel time between the nodes is determined using this distance and vehicle speed. For Toronto and Montréal, the graph represents a subset of the road network. Because Sherbrooke is a fairly small city, a graph representing its entire road network could be used.

For the cities of Toronto and Montréal, an evaluation of their actual routes and schedules was carried out. To do this, the information on drivers' work sheets had to be completed. With no data on real handling times, we had to estimate these times ourselves. The travel times between stops on the route were calculated using the stopping times indicated on the work sheets except when the vehicle was empty between two stops. In this case, the vehicle may have stopped to wait and the difference between the time at two stops includes travel time plus waiting time. Therefore, for two stops where the vehicle is empty, we compare the difference between the times at each stop with the travel time estimated on the network. If this is greater, we use the difference between actual stopping times as the travel time. Otherwise, we use our estimate on the network for the travel time, and we generate a waiting time for the vehicle.

4. TESTS WITH DATA FROM THE TORONTO WHEEL-TRANS SERVICE

In this section, we present the tests carried out with data for the day of 27th January 1983 for the Toronto Wheel-Trans Service. We begin this section by presenting the information treated. We continue with an evaluation of the actual routes and schedules used. Finally we present the results of several tests carried out on these data.

4.1 The information treated

4.1.1 Components of the complete network

We extracted the following municipalities from the linked AMS (Area Master Files) :

EAST YORK	(EASYK 102)
ETOBICOKE	(ETOBI 103)
NORTH YORK	(NORYK 105)
SCARBOROUGH	(SCARB 109)
TORONTO	(TORON 110)
YORK	(YORK 112)

This gives us a complete network of roads suitable for motor vehicles containing :

21 570 nodes
31 650 arcs
8 709 streets

4.1.2 Components of the aggregated network

From the components of the complete network and given a list of desired streets, we form an aggregated network. We used the streets contained in the file of addresses to be visited along with any main streets not represented on this file. This gave us an aggregated network with :

3 075 nodes
3 948 arcs
942 streets

With a network of this size, it is possible to work efficiently while maintaining adequate precision.

4.1.3 Stop location and creation of the distance table

1199 addresses had to be located. In an initial step, these addresses were located on nodes of the complete network. 891 nodes were chosen for theses addresses. In a second step, each of the 891 different nodes had to be associated with a node of the aggregated network. 543 nodes out of the 891 were already present in the aggregated network; for the remaining 348, we identified a new node on the aggregated network. In total, to locate the 891 nodes of the complete network in the aggregated network, 745 different nodes of the aggregated network were chosen.

1199 addresses

↓

891 nodes on the complete network

543 identical nodes

↓

745 nodes on the aggregated network

Using the aggregated network (internal structure), we calculated the distance table between the 745 nodes requires (terminal points).

4.1.4 Transportation requests

We considered two categories of users : regular users and occasional users (called pre-book requests, reservation requests).

The distribution of requests is as follows :

410 regular requests

686 occasional requests

For a total of 1096 requests.

4.1.5 Driver workdays

We have a total of 60 workdays, each made up of a single piece of work. There are 13 different types of workdays. For 37 workdays, the vehicle departure and arrival point is the Crockford garage and for 23 others, it is the Gurney garage.

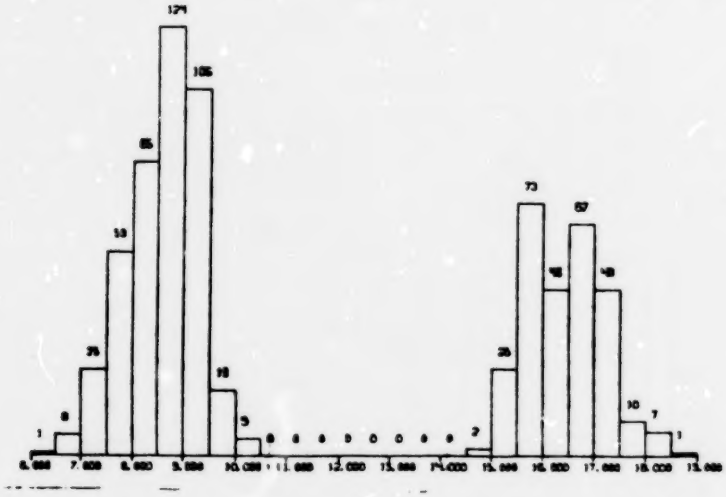
Workdays

Type of day	Number	Garage 1	Garage 2
06:00 19:30	9	6	3
06:00 18:30	23	12	11
06:00 18:00	1	1	0
06:00 14:30	2	1	1
06:30 19:30	1	0	1
06:30 19:00	3	3	0
06:30 15:00	3	1	2
07:00 19:30	3	3	0
07:30 19:00	3	1	2
12:30 24:00	2	2	0
14:30 24:00	7	4	3
14:30 23:30	1	1	0
18:00 24:00	2	2	0
	60	37	23

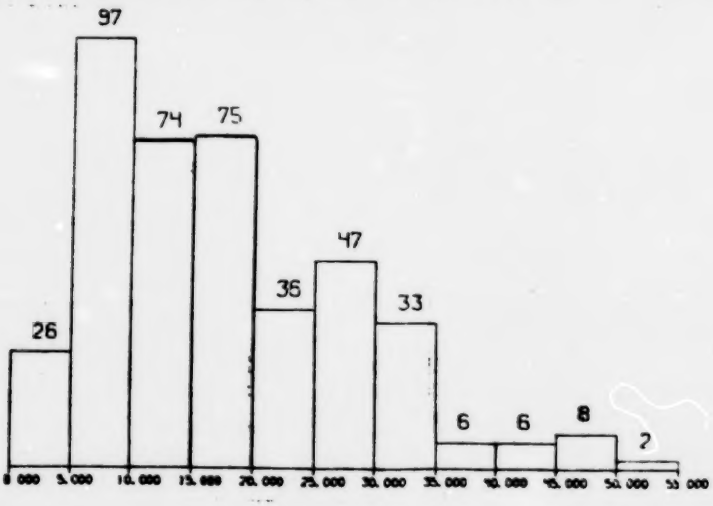
Garage 1 : Crockford Garage
Garage 2 Gurney Garage

4.2 Evaluation of the actual routes and schedules

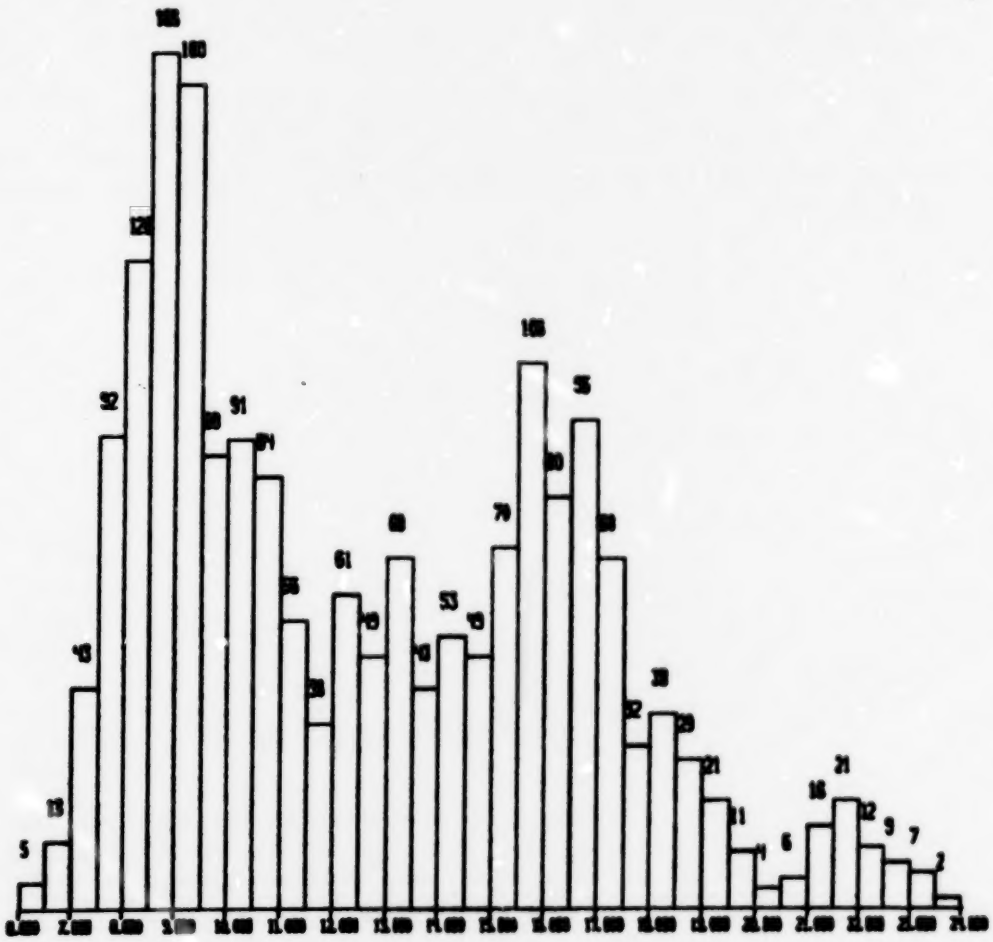
There are two types of users : regular and occasional. Regular requests are fairly stable. For the most part they are associated with travel to and from work or studies. So the transporter may plan routes and schedules in advance to serve this category of requests. Occasional requests for the operating day are added to these basic routes and schedules. For the day of 27th January 1983, there were 410 regular requests. These requests are concentrated in the morning and late afternoon. The histogram below illustrates the distribution of regular requests, assuming that requests are served at their ideal time. The histogram illustrates the number of requests with the same desired service time.



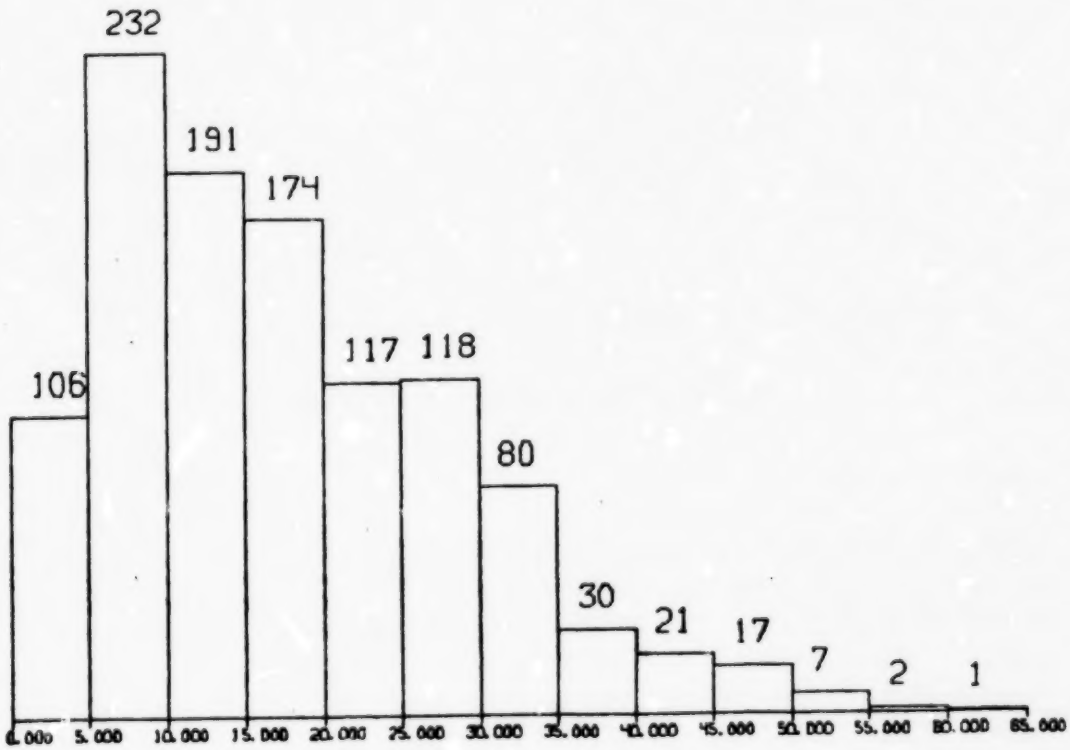
If we define the length of a request as the time required to go from the origin to the destination, we obtain an average lentgh for regular requests of 17.03 minutes. The histogram below illustrates the distribution of the length of regular requests.



The histogram below illustrates the distribution of all requests (regular and occasional - a total of 1096 requests), during the day with each rectangle representing the number of requests requiring the same service time.

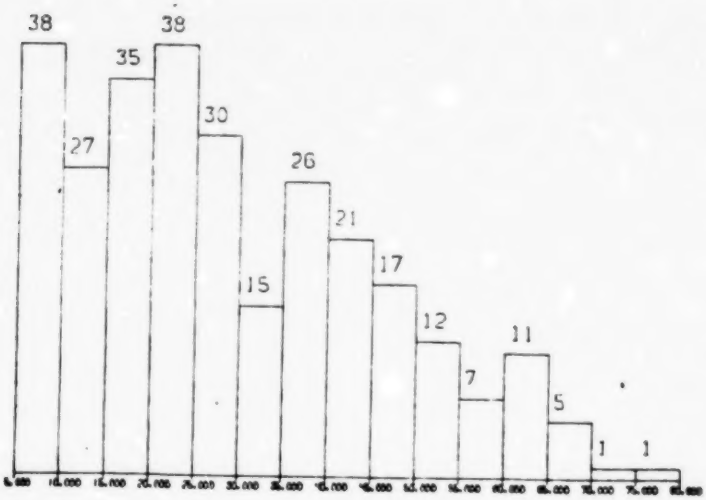


The histogram below illustrates the distribution of the length of all requests (regular and occasional); the average length of a request is of 17.07 minutes.



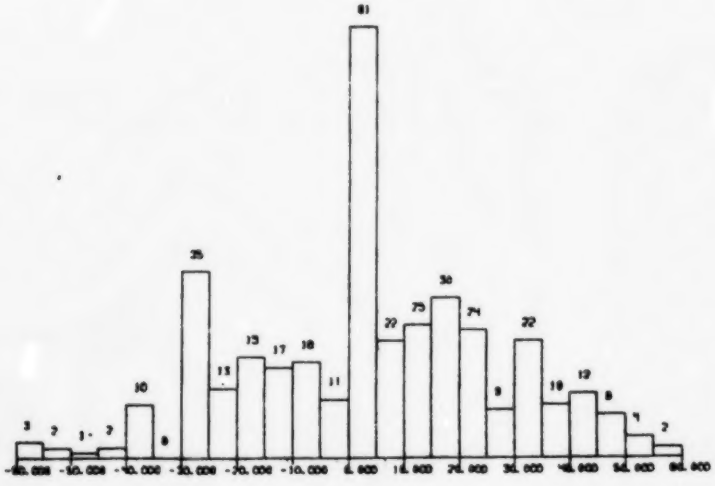
On pages 14 and 15, the 26 partial routes planned to serve the 410 regular requests are evaluated. The basic routes are completed and others are added to serve the additional 686 occasional requests. In total 60 routes were required to satisfy the 1096 requests. Pages 16 and 17 contain an evaluation of the 60 routes and schedules.

AVERAGE EXCESS TRAVEL TIME = 20.04
NUMBER OF REQUESTS WITH AN EXCESS TRAVEL TIME OF LESS THAN 5 MIN = 126



Distribution of excess travel time

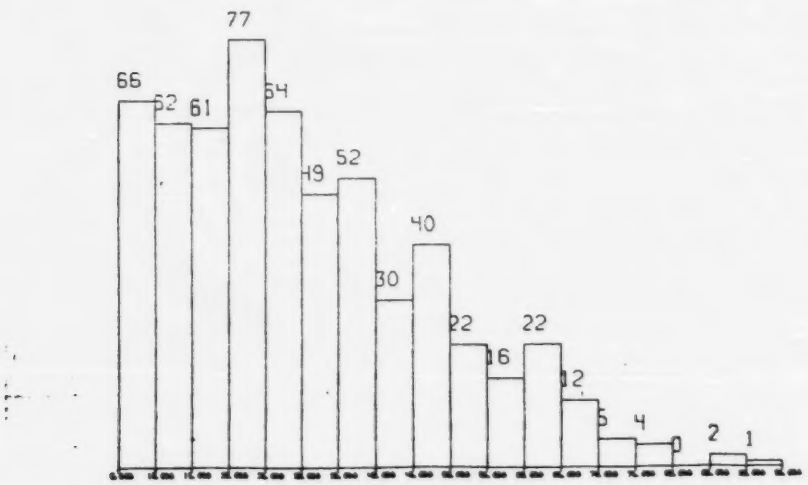
NUMBER OF REQUESTS	=	410
NUMBER OF PASSENGERS	=	413
NUMBER OF REQUESTS WHERE SERVICE TIME IS RESPECTED	=	270
AVERAGE DEVIATION FROM DESIRED SERVICE TIME	=	20.2
NUMBER OF REQUESTS WITH A DEVIATION GREATER THAN 60	=	21
NUMBER OF REQUESTS WHERE SERVICE TIME IS NOT RESPECTED	=	140
AVERAGE VIOLATION OF DESIRED SERVICE TIME	=	-27.5
NUMBER OF REQUESTS WHERE DEVIATION IS LESS THAN-60	=	9



Distribution of service delays

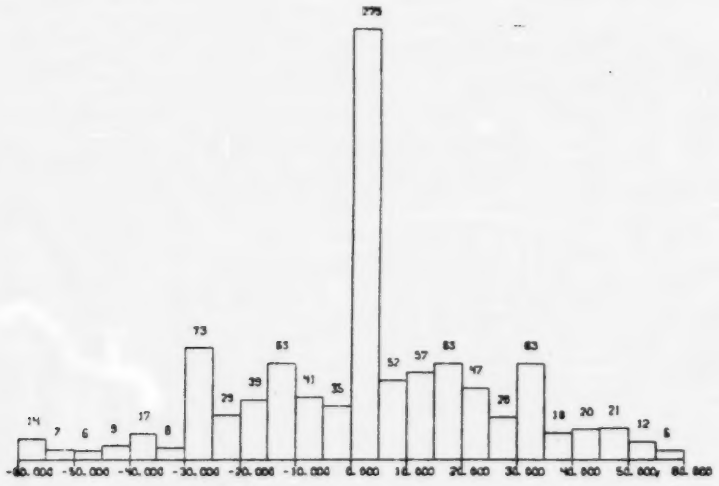
ROUTE PRODUCTIVITY				
Number of driver workdays				26
Number of routes				26
Total vehicle travel time				138h.42m.
Total vehicle travel time without passengers				31h.06m.
Total vehicle waiting time				155h.57m.
Total handling time				34h.30m.
STATISTICS	DPR	VPR	PPR	TVR
N	26	26	26	26
MEAN	1.25	2.38	2.90	1.06
MEDIAN	1.20	2.33	2.91	1.09
MINIMUM	0.89	1.73	2.17	0.71
MAXIMUM	2.00	3.07	4.11	1.40
1st QUARTILE	1.04	2.04	2.52	0.93
3rd QUARTILE	1.46	2.72	3.22	1.23
STANDARD DEVIATION	0.27	0.39	0.44	0.18

AVERAGE EXCESS TRAVEL TIME = 16.02
NUMBER OF REQUESTS WITH AN EXCESS TRAVEL TIME OF LESS THAN 5 MIN = 511



Distribution of excess travel time

NUMBER OF REQUESTS	=	1096
NUMBER OF PASSENGERS	=	1255
NUMBER OF REQUESTS WHERE SERVICE TIME IS RESPECTED	=	717
AVERAGE DEVIATION FROM DESIRED SERVICE TIME	=	17.6
NUMBER OF REQUESTS WITH A DEVIATION GREATER THAN 60	=	51
NUMBER OF REQUESTS WHERE SERVICE TIME IS NOT RESPECTED	=	379
AVERAGE VIOLATION OF DESIRED SERVICE TIME	=	-30.4
NUMBER OF REQUESTS WHERE DEVIATION IS LESS THAN -60	=	39



Distribution of service delays

ROUTE PRODUCTIVITY				
Number of driver workdays				60
Number of routes				60
Total vehicle travel time				472h.02m.
Total vehicle travel time without passengers				127h.46m.
Total vehicle waiting time				131h.12m.
Total handling time				90h.58m.
STATISTICS	DPR	VPR	PPR	TVR
N	60	60	60	60
MEAN	1.78	2.18	2.82	0.92
MEDIAN	1.76	2.17	2.73	0.90
MINIMUM	0.35	1.00	1.64	0.61
MAXIMUM	3.44	3.67	4.57	1.25
1st QUARTILE	1.48	1.92	2.50	0.79
3rd QUARTILE	2.08	2.47	3.15	1.05
STANDARD DEVIATION	0.50	0.45	0.50	0.16

4.3 Evaluation of our routes

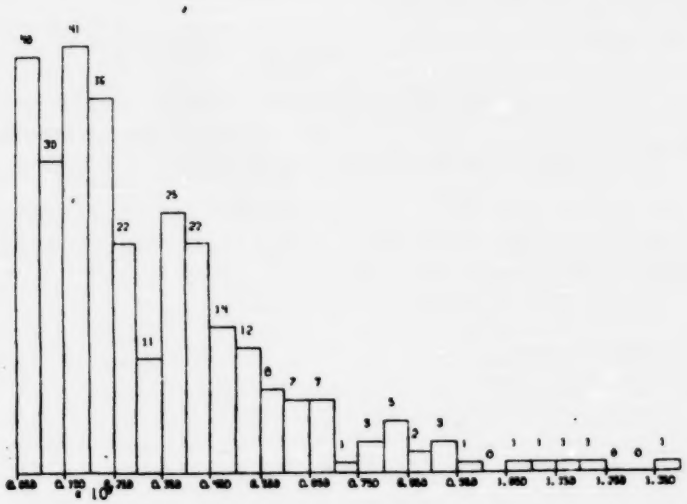
For these tests, we proceed in the same way as the transporter. We begin by constructing basic routes and schedules to serve 410 regular requests; occasional requests are added to these basic routes. For these tests, we assume an average speed of 31.8 km/hr. The handling times used for an ambulatory passenger and for a wheelchair are two and three minutes respectively. In the construction of basic routes and schedules for regular requests, we use no more than 26 drivers, the number used by the transporter for its own routes.

Pages 20 and 21 include an evaluation of service quality and productivity for the 26 routes and schedules constructed to serve the 110 regular requests. The constraint of satisfying all requests using only 26 drivers requires us to relax constraints on the quality of service. For 28% of requests, the desired service time is not respected. Passengers are either delivered after their desired arrival time, or picked up before their desired departure time. Furthermore, the average excess travel time is 23.12 minutes.

The following test carried out involved the construction of basic routes and schedules to satisfy regular requests without necessarily using only 26 drivers. The requests unsatisfied by the 26 basic routes were handled with the occasional requests and satisfied by the additional vehicles added. Pages 22 and 23 show the results obtained. We note a net improvement in terms of quality of service with the average excess travel time going from 23.12 minutes to 18.05 minutes. For all inserted requests, the type of service requested (departure or arrival) is respected. In addition to a better quality of service, vehicle productivity is improved. However 44 requests representing 10.7% of all requests could not be inserted into the 26 basic routes and had to be handled by other vehicles along with the occasional requests.

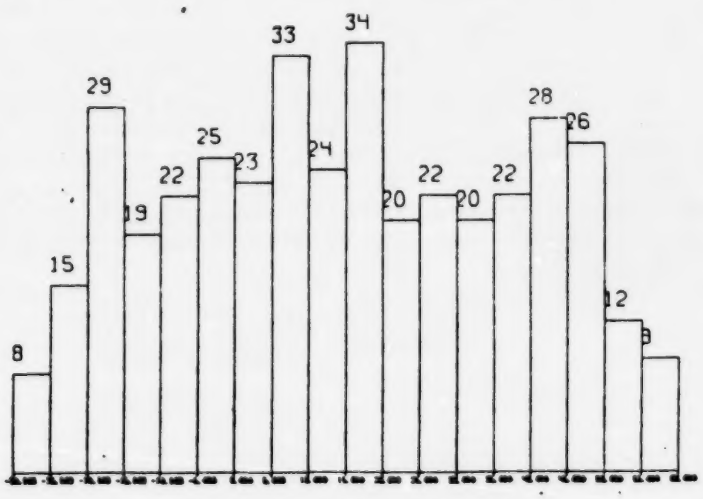
The last test carried out with the Toronto data involved the completion of the 26 basic routes with routes to cover the occasional requests plus the 44 regular requests not covered by our 26 basic routes. Twenty-four (24) new routes had to be added for a total of 50. For 139 requests, the type of service is not respected (arrival or departure). This represents 12.7% of requests. Furthermore, using only 50 driver workdays, only 4 occasional requests out of 686 were not inserted. Pages 24 and 25 show the details of the evaluation of our 50 routes and schedules.

AVERAGE EXCESS TRAVEL TIME = 23.12
NUMBER OF REQUESTS WITH AN EXCESS TRAVEL TIME OF LESS THAN 5 MIN = 115



Distribution of excess travel time

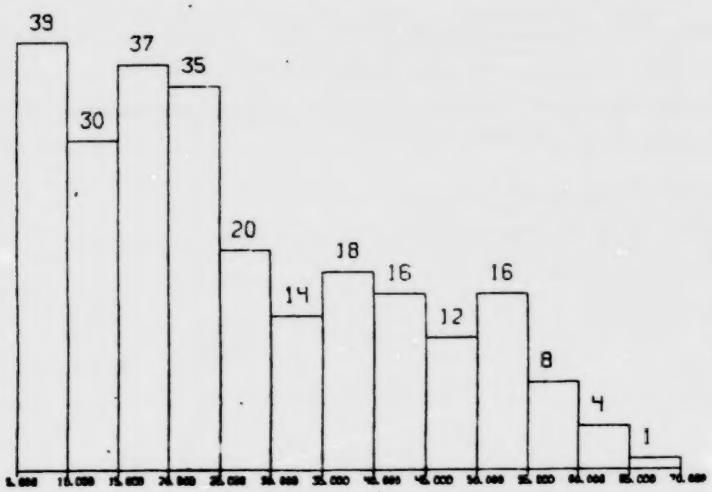
NUMBER OF REQUESTS	=	410
NUMBER OF PASSENGERS	=	413
NUMBER OF REQUESTS WHERE SERVICE TIME IS RESPECTED	=	292
AVERAGE DEVIATION FROM DESIRED SERVICE TIME	=	29.31
NUMBER OF REQUESTS WITH A DEVIATION GREATER THAN 60	=	19
NUMBER OF REQUESTS WHERE SERVICE TIME IS NOT RESPECTED	=	118
AVERAGE VIOLATION OF DESIRED SERVICE TIME	=	-13.60
NUMBER OF REQUESTS WHERE DEVIATION IS LESS THAN-60	=	0



Distribution of service delays

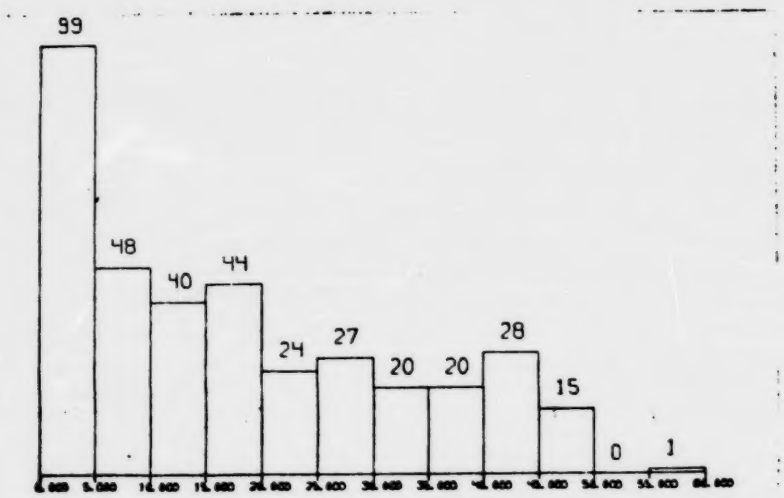
ROUTE PRODUCTIVITY				
Number of driver workdays				26
Number of routes				26
Total vehicle travel time				133h.23m.
Total vehicle travel time without passengers				38h.43m.
Total vehicle waiting time				132h.20m.
Total handling time				34h.30m.
STATISTICS	DPR	VPR	PPR	TVR
N	26	26	26	26
MEAN	1.32	2.49	3.30	1.16
MEDIAN	1.24	2.45	3.17	1.15
MINIMUM	0.72	1.36	1.83	0.90
MAXIMUM	1.92	3.92	4.87	1.58
1st QUARTILE	1.11	2.03	2.68	1.04
3rd QUARTILE	1.62	2.90	3.89	1.29
STANDARD DEVIATION	0.32	0.64	0.85	0.18

AVERAGE EXCESS TRAVEL TIME = 18.05
NUMBER OF REQUESTS WITH AN EXCESS TRAVEL TIME OF LESS THAN 5 MIN = 116



Distribution of excess travel time

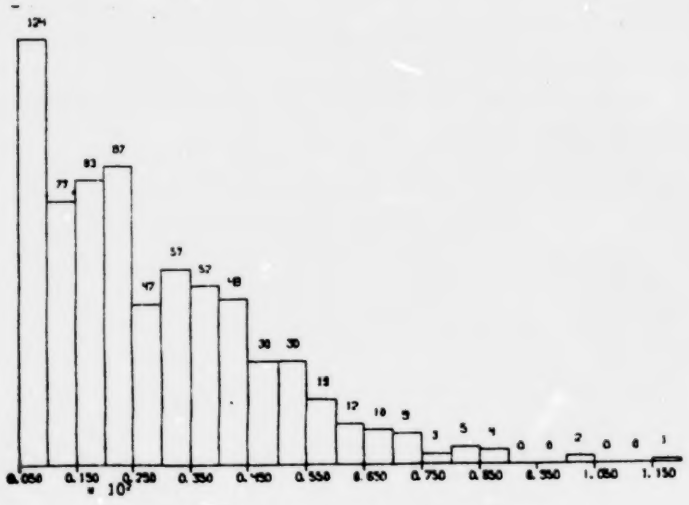
NUMBER OF REQUESTS	= 366
NUMBER OF PASSENGERS	= 368
NUMBER OF REQUESTS WHERE SERVICE TIME IS RESPECTED	= 366
AVERAGE DEVIATION FROM DESIRED SERVICE TIME	= 17.21
NUMBER OF REQUESTS WITH A DEVIATION GREATER THAN 60	= 0
NUMBER OF REQUESTS WHERE SERVICE TIME IS NOT RESPECTED	= 0
AVERAGE VIOLATION OF DESIRED SERVICE TIME	= 0,0
NUMBER OF REQUESTS WHERE DEVIATION IS LESS THAN -60	= 0



Distribution of service delays

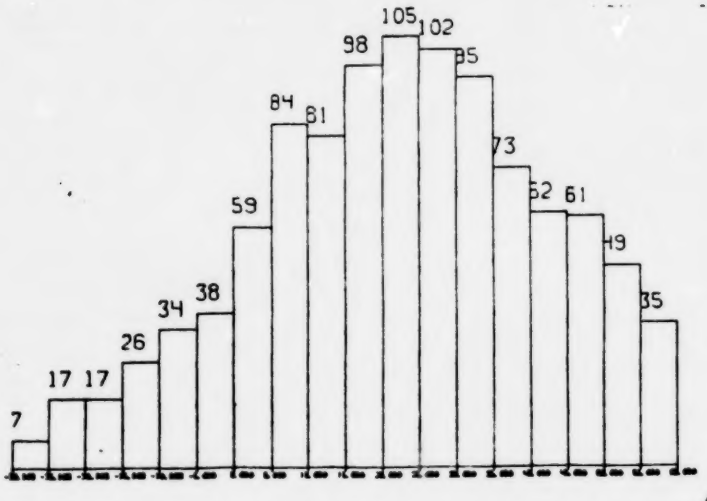
ROUTE PRODUCTIVITY				
Number of driver workdays				26
Number of routes				26
Total vehicle travel time				116h.31m.
Total vehicle travel time without passengers				38h.37m.
Total vehicle waiting time				153h.44m.
Total handling time				30h.50m.
STATISTICS	DPR	VPR	PPR	TVR
N	26	26	26	26
MEAN	1.18	2.53	3.47	1.17
MEDIAN	1.12	2.54	3.50	1.13
MINIMUM	0.63	1.37	2.07	0.90
MAXIMUM	1.84	4.12	5.32	1.64
1st QUARTILE	0.96	2.00	2.71	1.00
3rd QUARTILE	1.48	3.03	4.28	1.28
STANDARD DEVIATION	0.33	0.74	0.95	0.20

AVERAGE EXCESS TRAVEL TIME = 18.13
NUMBER OF REQUESTS WITH AN EXCESS TRAVEL TIME OF LESS THAN 5 MIN = 392



Distribution of excess travel time

NUMBER OF REQUESTS	= 1092
NUMBER OF PASSENGERS	= 1251
NUMBER OF REQUESTS WHERE SERVICE TIME IS RESPECTED	= 953
AVERAGE DEVIATION FROM DESIRED SERVICE TIME	= 28.53
NUMBER OF REQUESTS WITH A DEVIATION GREATER THAN 60	= 49
NUMBER OF REQUESTS WHERE SERVICE TIME IS NOT RESPECTED	= 139
AVERAGE VIOLATION OF DESIRED SERVICE TIME	= -11.42
NUMBER OF REQUESTS WHERE DEVIATION IS LESS THAN -60	= 0



Distribution of service delays

ROUTE PRODUCTIVITY				
Number of driver workdays				50
Number of routes				50
Total vehicle travel time				415h.22m.
Total vehicle travel time without passengers				135h.21m.
Total vehicle waiting time				63h.18m.
Total handling time				90h.34m.
STATISTICS	DPR	VPR	PPR	TVR
N	50	50	50	50
MEAN	2.10	2.44	3.36	1.08
MEDIAN	2.00	2.50	3.34	1.07
MINIMUM	0.72	1.16	1.86	0.79
MAXIMUM	3.60	3.66	5.57	1.46
1st QUARTILE	1.65	1.87	2.63	0.99
3rd QUARTILE	2.74	2.95	4.03	1.15
STANDARD DEVIATION	0.70	0.64	0.85	0.14

5. TESTS WITH DATA FROM THE MONTREAL URBAN COMMUNITY TRANSIT COMMISSION

We describe the data for the day 19th January 1983 for the Montreal Urban Community Transit Commission (MUCTC). After describing the data, we present an evaluation of the MUCTC's routes and schedules for regular requests before 09:00 and for all requests. We conclude this section by presenting the results we obtained on the same data.

5.1 Information treated

5.1.1 Components of the complete network

The MUCTC serves the whole island of Montréal including the following municipalities extracted from the AMF (Area Master File) :

Anjou	(Anjou 1)	Saint-Luc	(Stluc15)
Saint-Léonard	(Stléo1)	Montréal-Ouest	(Mtlou15)
Dorval	(Dorv14)	Hampstead	(Hams15)
Lachine	(Lachi4)	Mont-Royal	(Mtroy16)
Beaconsfield	(Bcfld6)	Outremont	(Outrm16)
Kirkland	(Kirk6)	Roxboro	(Roxbo17)
Verdun	(Verdu7)	Sainte-Geneviève	(Stege17)
LaSalle	(Lasal7)	Pierrefonds	(Piefd17)
Montréal	(Mtl11)	Dollard-des-Ormeaux	(Ddo18)
Westmount	(Westmt11)	Pointe-Claire	(Ptcla18)
Montréal	(Mtl12)	Baie d'Urfé	(Burfe19)
Pointe-aux-Trembles	(PAT13)	Ste-Anne-de-Bellevue	(Sabel19)
Montréal-Est	(Mtles13)	Senneville	(Senel19)
Montréal-Nord	(Mtlnd14)	Saint-Laurent	(Stlau23)
Saint-Pierre	(Stpie15)		

The 29 municipalities form a complete network of roads suitable for motor vehicles of :

19 258 nodes (intersections)
29 508 arcs (street segments)
6 063 streets

5.1.2 Components of the aggregated network

Based on the components of the complete network and with a list of desired streets, we select an aggregated network. The aggregated network used for Montréal contains :

4579 nodes,

5673 arcs,

1274 streets.

5.1.3 Location of stops and creation of the distance table

We had 705 addresses to be located. In an initial step, these addresses were located at nodes of the complete network. 629 different nodes were required to locate 705 addresses. In a second step, a node of the aggregated network was associated with each of the 629 nodes of the complete network; 296 out of the 629 nodes were already present in the aggregated network. To locate the remaining 333 nodes, 285 nodes of the aggregated network were selected. Altogether, 581 nodes of the aggregated network were required to locate the 705 addresses.

705 adresses
↓
629 nodes of the complete network

333 not present in the aggregated network

296 already in the aggregated network

285 nodes in the aggregated network

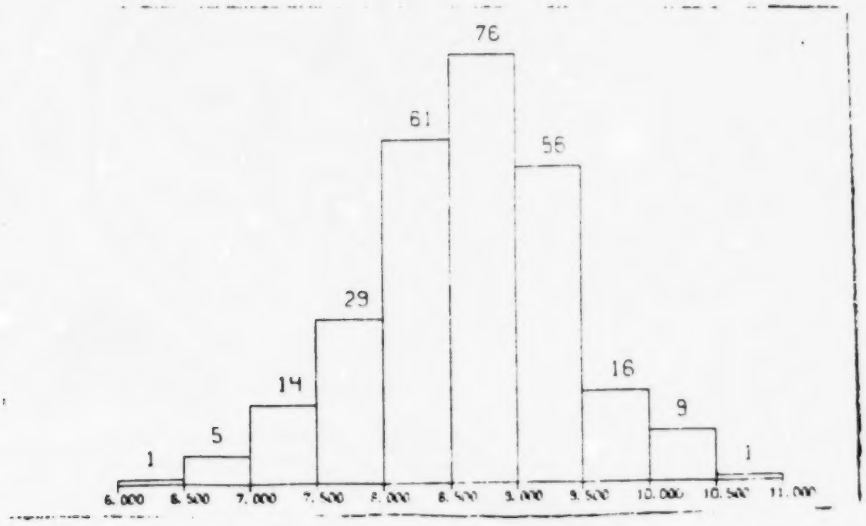
5.1.4 The transportation requests

The MUCTC distinguishes two categories of users : regular users and occasional users. Basic routes are planned to serve regular users requesting service before 09.00. The remaining of regular and occasional requests are added to these initialized routes.

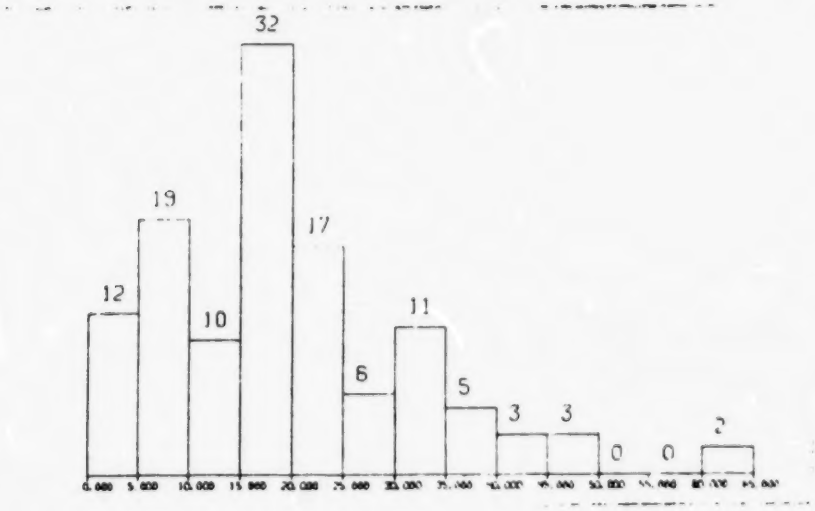
120 regular requests for morning service
155 regular requests for afternoon service
305 occasional requests

For a total of 580 requests.

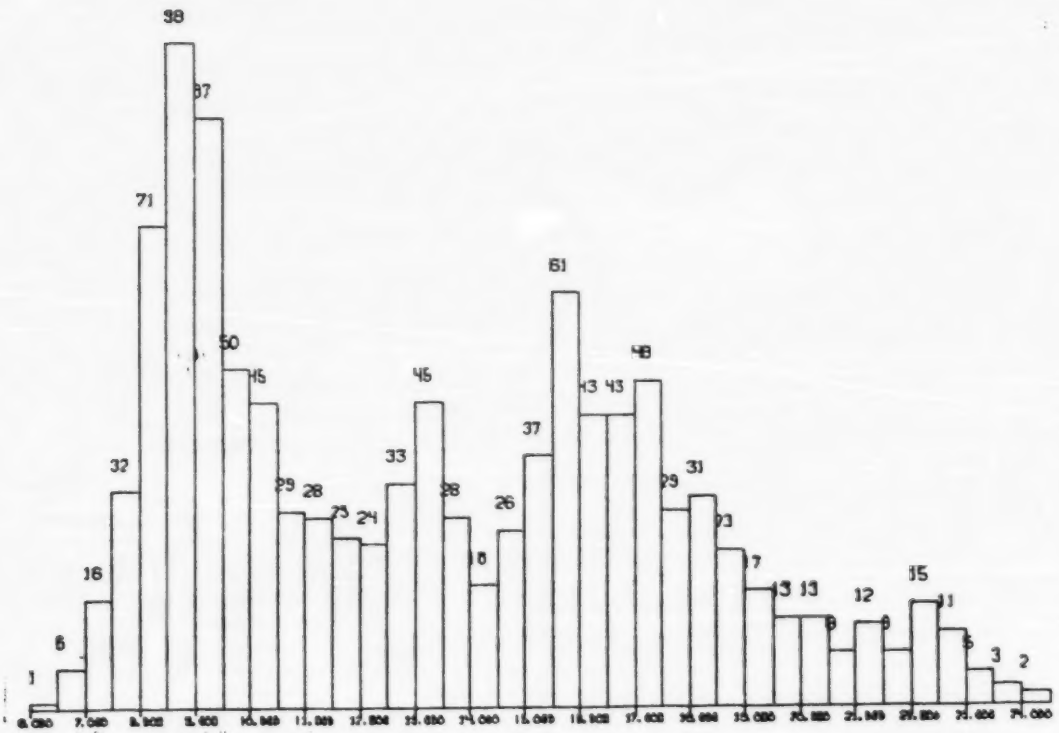
The histogram below shows the distribution of regular requests requiring morning service. The number of requests requiring service at the same time is indicated.



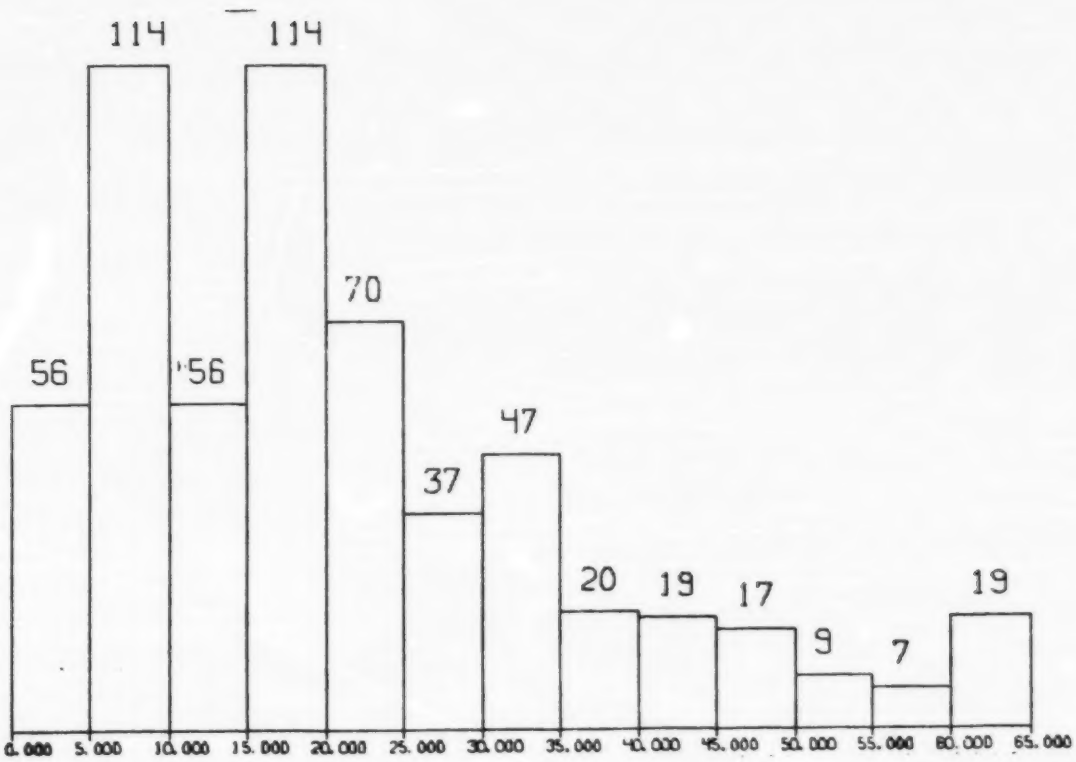
If the length of a request is defined as the time required to go from the origin to the destination, we obtain an average length for regular morning requests of 19.18 minutes.



The histogram below illustrates the distribution of all requests (regular and occasional).

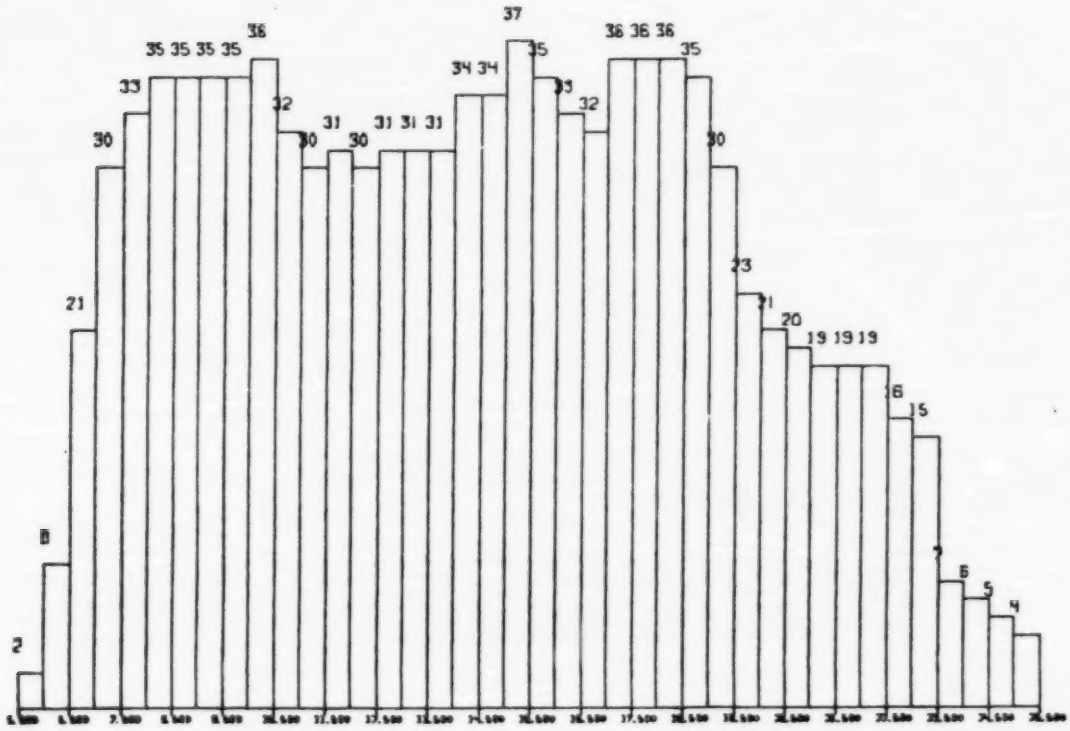


The histogram below illustrates the distribution of lengths of all the requests; the average length of a request is 20.58 minutes.



5.1.5 Drivers workdays

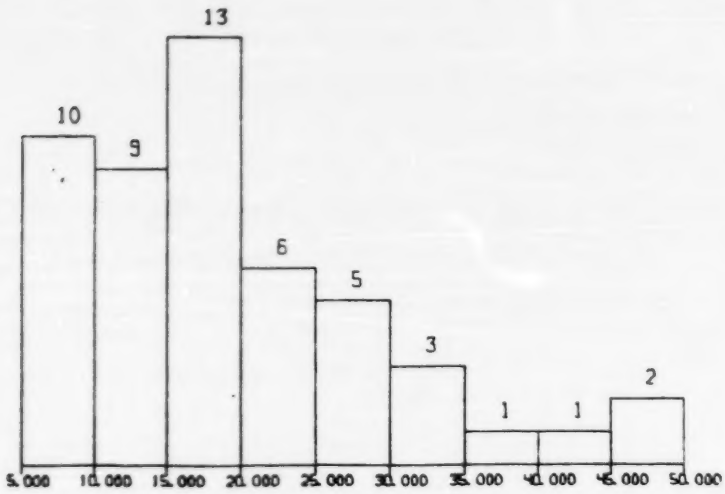
For this operating day, we have 62 8-hour driver workdays. Some are made up of a single piece of work and some have two. The vehicle departure point and arrival point is the same for all drivers (the garage at 5590 Casgrain). At the beginning and end of each piece of work, five minutes is allocated to the driver. The histogram below shows the number of drivers available for routes during the day.



5.2 Evaluation of the MUCTC's routes

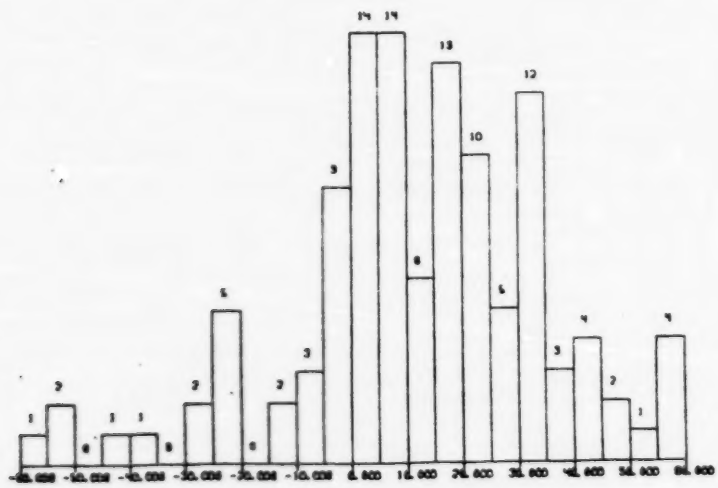
On pages 33 and 34, we present an evaluation of the 35 partial routes planned by the transporter to serve the 120 regular morning requests. These basic routes are completed and other are added to serve the 460 remaining requests. In total, for the operating day, 62 drivers are required to serve the 580 requests (701 passengers). Pages 35 and 36 contain an evaluation of the routes and schedules used by the transporter.

AVERAGE EXCESS TRAVEL TIME = 7.84
NUMBER OF REQUESTS WITH AN EXCESS TRAVEL TIME OF LESS THAN 5 MIN = 70



Distribution of excess travel time

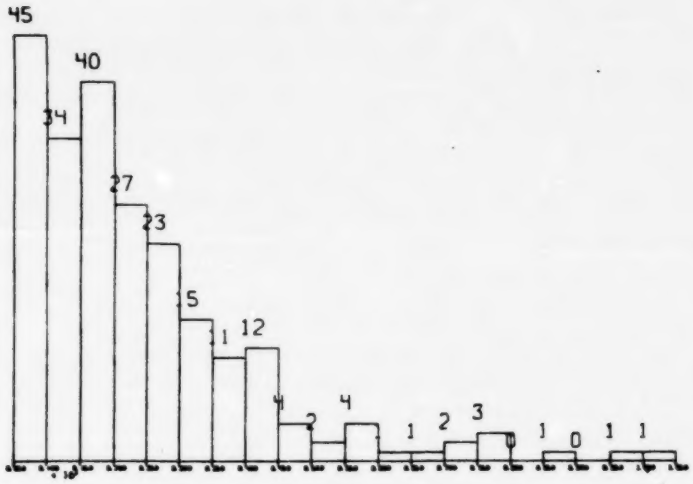
NUMBER OF REQUESTS	= 120
NUMBER OF PASSENGERS	= 127
NUMBER OF REQUESTS WHERE SERVICE TIME IS RESPECTED	= 93
AVERAGE DEVIATION FROM DESIRED SERVICE TIME	= 21.43
NUMBER OF REQUESTS WITH A DEVIATION GREATER THAN 60	= 5
NUMBER OF REQUESTS WHERE SERVICE TIME IS NOT RESPECTED	= 27
AVERAGE VIOLATION OF DESIRED SERVICE TIME	= -21.70
NUMBER OF REQUESTS WHERE DEVIATION IS LESS THAN -60	= 1



Distribution of service delays

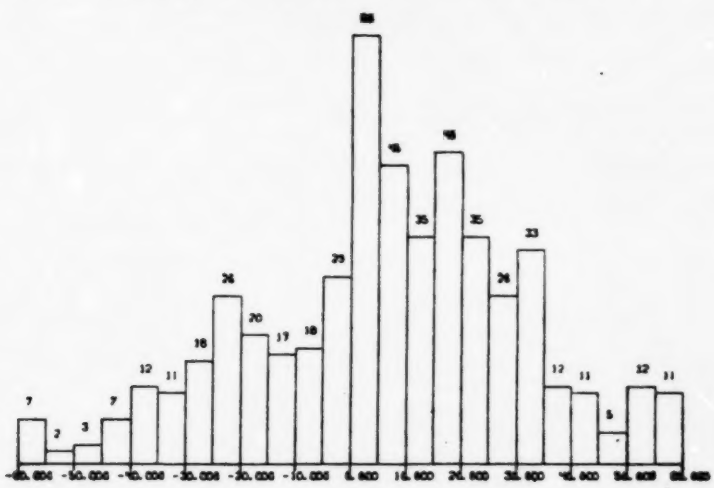
ROUTE PRODUCTIVITY				
Number of driver workdays				35
Number of routes				35
Total vehicle travel time				54h.50m.
Total vehicle travel time without passengers				20h.51m.
Total vehicle waiting time				165h.27m.
Total handling time				10h.48m.
STATISTICS	DPR	VPR	PPR	TVR
N	35	35	35	35
MEAN	0.59	1.98	2.83	1.05
MEDIAN	0.50	1.87	2.67	1.02
MINIMUM	0.12	1.09	1.70	0.67
MAXIMUM	1.75	4.34	5.90	1.82
1st QUARTILE	0.37	1.44	2.12	0.77
3rd QUARTILE	0.75	2.22	3.30	1.22
STANDARD DEVIATION	0.34	0.68	0.83	0.30

AVERAGE EXCESS TRAVEL TIME = 9.22
NUMBER OF REQUESTS WITH AN EXCESS TRAVEL TIME OF LESS THAN 5 MIN = 358



Distribution of excess travel time

NUMBER OF REQUESTS	= 580
NUMBER OF PASSENGERS	= 701
NUMBER OF REQUESTS WHERE SERVICE TIME IS RESPECTED	= 374
AVERAGE DEVIATION FROM DESIRED SERVICE TIME	= 24.37
NUMBER OF REQUESTS WITH A DEVIATION GREATER THAN 60	= 39
NUMBER OF REQUESTS WHERE SERVICE TIME IS NOT RESPECTED	= 206
AVERAGE VIOLATION OF DESIRED SERVICE TIME	= -38.07
NUMBER OF REQUESTS WHERE DEVIATION IS LESS THAN -60	= 38



Distribution of service delays

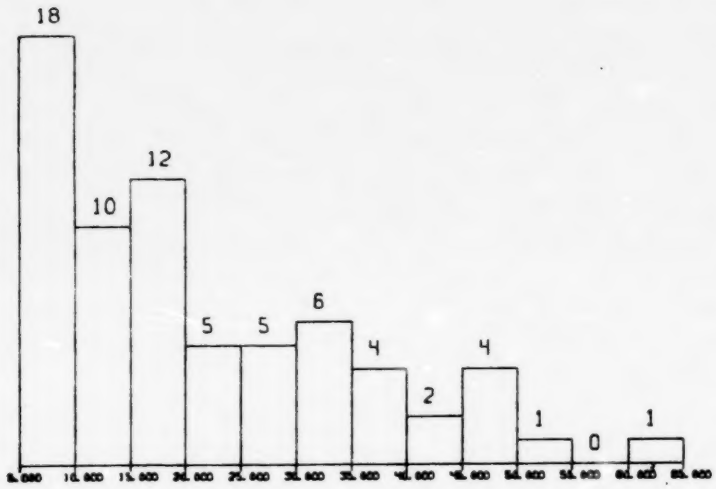
ROUTE PRODUCTIVITY				
Number of driver workdays				62
Number of routes				71
Total vehicle travel time				280h.24m.
Total vehicle travel time without passengers				88h.55m.
Total vehicle waiting time				127h.49m.
Total handling time				55h.16m.
STATISTICS	DPR	VPR	PPR	TVR
N	62	62	62	62
MEAN	1.46	2.10	2.85	1.05
MEDIAN	1.37	2.02	2.72	1.03
MINIMUM	0.62	0.99	1.49	0.65
MAXIMUM	3.62	4.65	5.54	1.66
1st QUARTILE	1.12	1.64	2.26	0.91
3rd QUARTILE	1.65	2.42	3.18	1.16
STANDARD DEVIATION	0.54	0.66	0.81	0.22

5.3 Evaluation or our routes

We begin by constructing basic routes and schedules for the 120 regular morning requests. We add the remaining requests to these basic routes. For these tests, we use 21km/hr. as the average speed of vehicles. The handling times for an ambulatory passenger and a wheelchair are two and three minutes respectively. In these tests, we require the type of service requested to be respected. Thus, no passenger requiring a specific arrival time will be delivered after this time. Three requests were dropped, because their desired arrival times were too early in the day. 28 routes were initialized to serve the 124 passengers. The average excess travel time is 12.28 minutes and the type of service is respected with an average deviation from the desired time of 18.54. Pages 38 and 39 give the details of this evaluation.

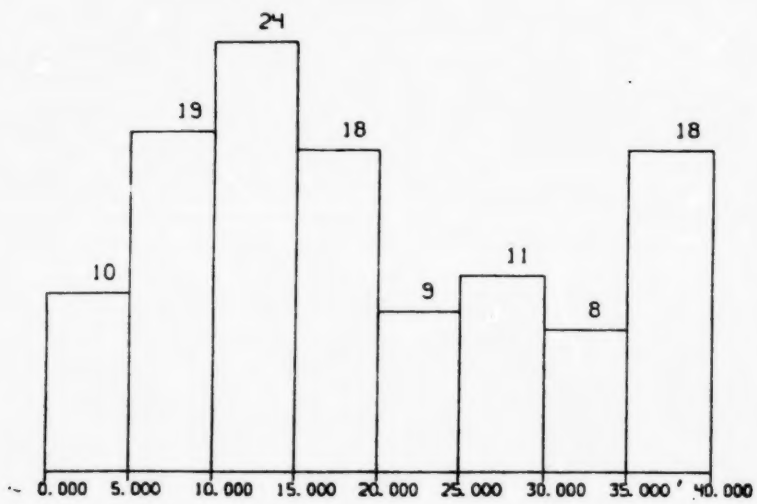
The basic 28 routes are completed by adding the remaining regular requests and the occasional requests. New routes must be initialized to service these requests. In total, 46 drivers are required. The quality of service offered for occasional requests is excellent. The details of these results are given on pages 40 and 41.

AVERAGE EXCESS TRAVEL TIME = 12.28
NUMBER OF REQUESTS WITH AN EXCESS TRAVEL TIME OF LESS THAN 5 MIN = 49



Distribution of excess travel time

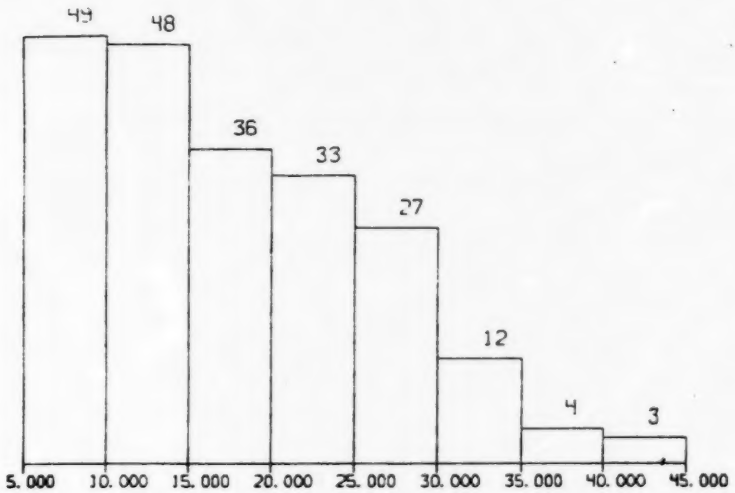
NUMBER OF REQUESTS	= 117
NUMBER OF PASSENGERS	= 124
NUMBER OF REQUESTS WHERE SERVICE TIME IS RESPECTED	= 117
AVERAGE DEVIATION FROM DESIRED SERVICE TIME	= 18.54
NUMBER OF REQUESTS WITH A DEVIATION GREATER THAN 60	= 0
NUMBER OF REQUESTS WHERE SERVICE TIME IS NOT RESPECTED	= 0
AVERAGE VIOLATION OF DESIRED SERVICE TIME	= 0.0
NUMBER OF REQUESTS WHERE DEVIATION IS LESS THAN -60	= 0



Distribution of service delays

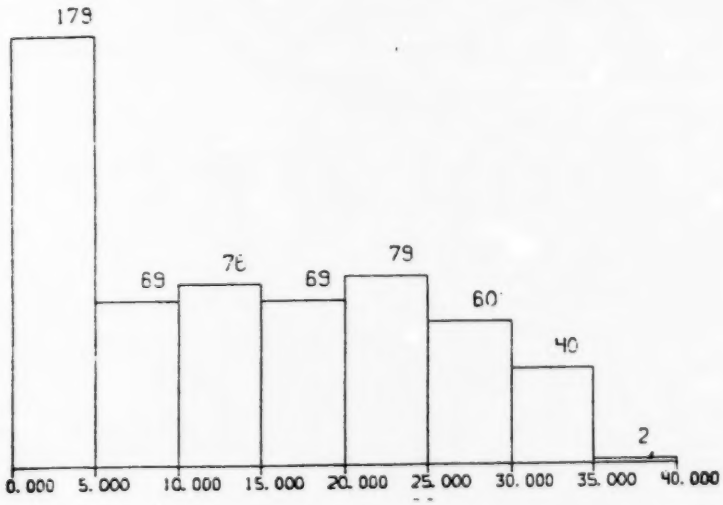
ROUTE PRODUCTIVITY				
Number of driver workdays				28
Number of routes				28
Total vehicle travel time				60h.34m.
Total vehicle travel time without passengers				29h.25m.
Total vehicle waiting time				105h.49m.
Total handling time				10h.34m.
STATISTICS	DPR	VPR	PPR	TVR
N	28	28	28	28
MEAN	0.77	1.73	2.79	1.11
MEDIAN	0.75	1.57	2.64	1.05
MINIMUM	0.12	0.37	0.87	0.68
MAXIMUM	3.25	4.06	5.62	1.76
1st QUARTILE	0.34	1.04	1.96	1.00
3rd QUARTILE	0.87	2.45	3.40	1.19
STANDARD DEVIATION	0.65	0.93	1.10	0.25

AVERAGE EXCESS TRAVEL TIME = 6.59
NUMBER OF REQUESTS WITH AN EXCESS TRAVEL TIME OF LESS THAN 5 MIN = 362



Distribution of excess travel time

NUMBER OF REQUESTS	= 574
NUMBER OF PASSENGERS	= 689
NUMBER OF REQUESTS WHERE SERVICE TIME IS RESPECTED	= 574
AVERAGE DEVIATION FROM DESIRED SERVICE TIME	= 13.23
NUMBER OF REQUESTS WITH A DEVIATION GREATER THAN 60	= 0
NUMBER OF REQUESTS WHERE SERVICE TIME IS NOT RESPECTED	= 0
AVERAGE VIOLATION OF DESIRED SERVICE TIME	= 0.0
NUMBER OF REQUESTS WHERE DEVIATION IS LESS THAN -60	= 0



Distribution of service delays

ROUTE PRODUCTIVITY				
Number of driver workdays				46
Number of routes				64
Total vehicle travel time				204h.18m.
Total vehicle travel time without passengers				82h.36m.
Total vehicle waiting time				39h.10m.
Total handling time				54h.06m.
STATISTICS	DPR	VPR	PPR	TVR
N	46	46	46	46
MEAN	1.87	2.59	3.84	1.39
MEDIAN	1.87	2.60	3.96	1.35
MINIMUM	0.12	0.79	1.79	1.06
MAXIMUM	3.50	4.02	6.19	1.97
1st QUARTILE	1.50	2.02	3.18	1.24
3rd QUARTILE	2.37	3.10	4.41	1.53
STANDARD DEVIATION	0.75	0.78	0.96	0.20

6. TESTS WITH DATA FROM THE SHERBROOKE MUNICIPAL TRANSIT CORPORATION

We present data for the day of 14th October 1983 for the Sherbrooke Municipal Transit Corporation. The Corporation serves the municipalities of Sherbrooke, Ascot, Fleurimont, Lennoxville and Rock Forest.

6.1 Information treated

6.1.1 The components of the complete network

For the city of Sherbrooke, we used the geodoced road network for school transportation. The complete network is small enough that we could work with it directly without creating an aggregated network.

The complete network contains :

2380 nodes (intersection)
3247 arcs (street segments)
1297 streets.

6.1.2 Location of stops and creation of the distance table

To locate the 262 addresses, 187 nodes of the complete network were selected. Using the complete network, we determine the distance table between these 187 nodes (points).

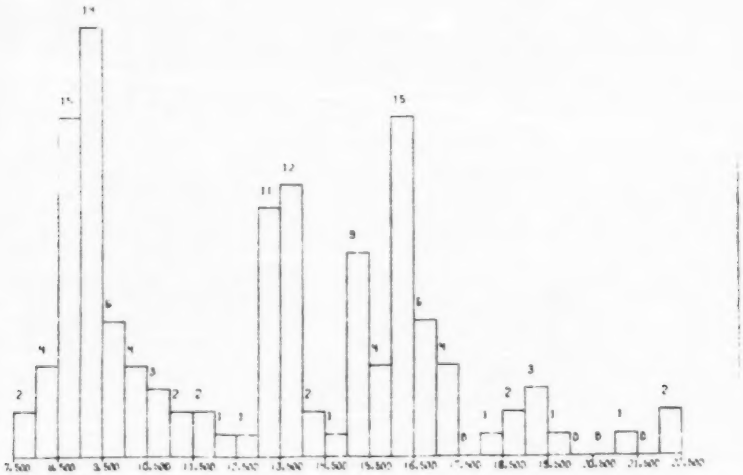
6.1.3 Transportation requests

The distribution of requests is as follows :

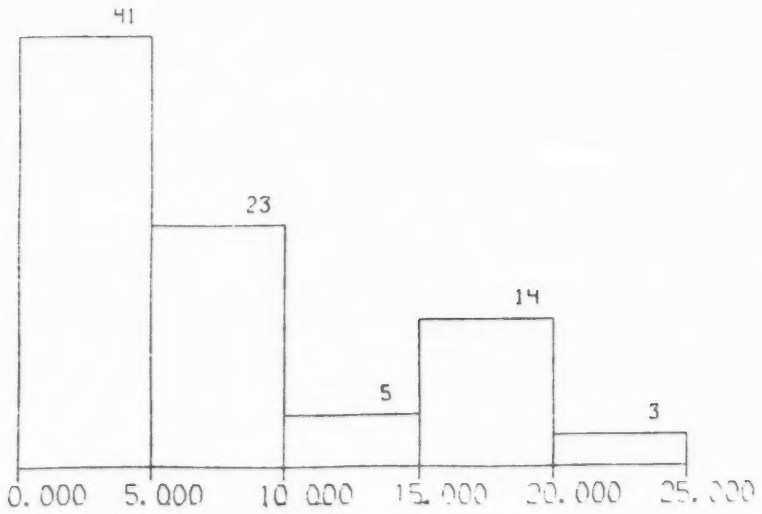
57 regular requests
29 occasional requests

for a total of 86 requests.

The distribution of the 86 requests overtime is illustrated in the histogram below.



Assuming an average speed of 30 km/hr, the average length of a request is seven minutes. This time does not include handling time. The following histogram illustrates the distribution of the length of requests.



6.1.4 Driver workdays

The municipal corporation, for the day of 14th October 1982, used six drivers, three of whom worked ten hours and three worked eight hours.

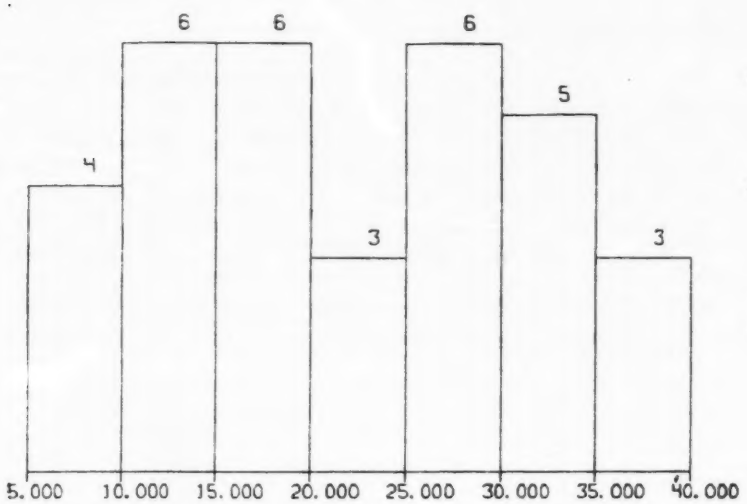
Type of day	Number	Duration
07:00-12:00, 13:00-18:00	2	10
07:00-11:00, 12:00-18:00	1	10
08:00-11:00, 14:00-19:00	1	8
11:30-14:30, 18:00-23:00	1	8
15:00-18:00, 19:00-24:00	1	8

Vehicles all used the same garage for departures and arrivals (i.e. 895 CABANA SHERB.

6.2 Evaluation of our routes

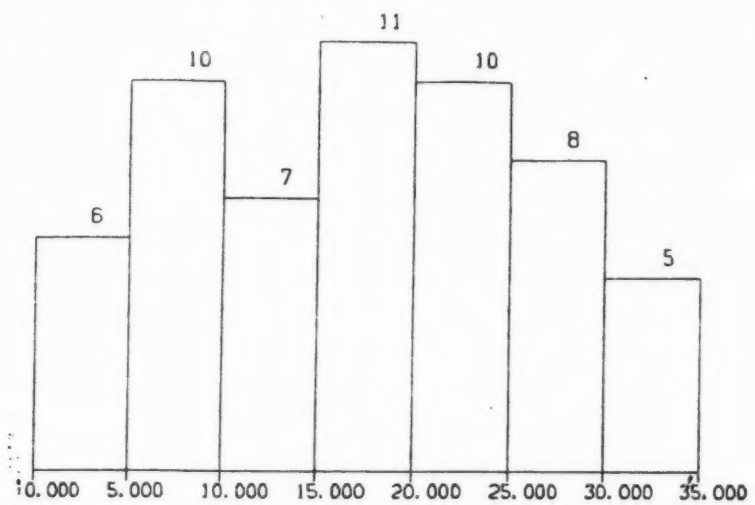
We begin by creating basic routes and schedules for the 57 regular requests for the day of 14th Octobre 1982. We use an average speed of 30 km/hr to evaluate travel times. The handling times used were two minutes for an ambulatory passenger and three minutes for a wheel-chair. The type of service requested (desired departure or arrival) is always respected and the service delay is 35 minutes maximum. Pages 48 and 49 contain an evaluation of the eight partial routes created to server the regular requests. We complete these eight routes and create two new ones to serve the occasional requests. Details of the ten routes required to serve the 95 passengers are given on pages 50 and 51.

AVERAGE EXCESS TRAVEL TIME = 13.14
NUMBER OF REQUESTS WITH AN EXCESS TRAVEL TIME OF LESS THAN 5 MIN = 24



Distribution of excess travel time

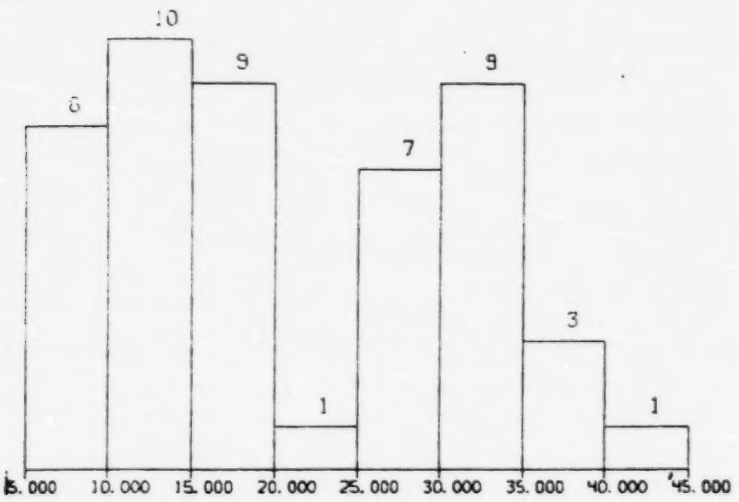
NUMBER OF REQUESTS	=	57
NUMBER OF PASSENGERS	=	61
NUMBER OF REQUESTS WHERE SERVICE TIME IS RESPECTED	=	57
AVERAGE DEVIATION FROM DESIRED SERVICE TIME	=	16.63
NUMBER OF REQUESTS WITH A DEVIATION GREATER THAN 60	=	0
NUMBER OF REQUESTS WHERE SERVICE TIME IS NOT RESPECTED	=	0
AVERAGE VIOLATION OF DESIRED SERVICE TIME	=	0.0
NUMBER OF REQUESTS WHERE DEVIATION IS LESS THAN -60	=	0



Distribution of service delays

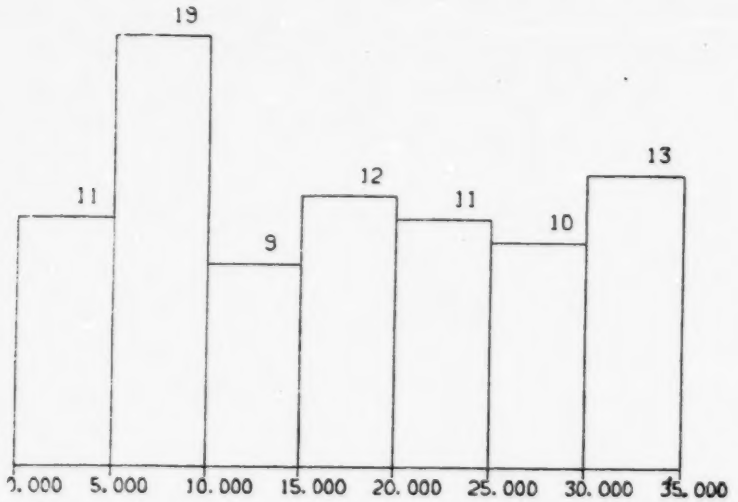
ROUTE PRODUCTIVITY				
Number of driver workdays				4
Number of routes				8
Total vehicle travel time				10h.39m.
Total vehicle travel time without passengers				3h.35m.
Total vehicle waiting time				14h.23m.
Total handling time				5h.12m.
STATISTICS	DPR	VPR	PPR	TVR
N	4	4	4	4
MEAN	1.70	3.90	5.17	1.05
MEDIAN	1.75	3.94	5.09	1.05
MINIMUM	1.10	2.99	3.63	0.96
MAXIMUM	2.20	4.75	6.88	1.15
1st QUARTILE	1.17	3.18	3.94	0.98
3rd QUARTILE	2.18	4.59	6.49	1.13
STANDARD DEVIATION	0.55	0.74	1.34	0.08

AVERAGE EXCESS TRAVEL TIME = 12.19
NUMBER OF REQUESTS WITH AN EXCESS TRAVEL TIME OF LESS THAN 5 MIN = 37



Distribution of excess travel time

NUMBER OF REQUESTS	=	85
NUMBER OF PASSENGERS	=	95
NUMBER OF REQUESTS WHERE SERVICE TIME IS RESPECTED	=	85
AVERAGE DEVIATION FROM DESIRED SERVICE TIME	=	16.27
NUMBER OF REQUESTS WITH A DEVIATION GREATER THAN 60	=	0
NUMBER OF REQUESTS WHERE SERVICE TIME IS NOT RESPECTED	=	0
AVERAGE VIOLATION OF DESIRED SERVICE TIME	=	0.0
NUMBER OF REQUESTS WHERE DEVIATION IS LESS THAN -60	=	0



Distribution of service delays

ROUTE PRODUCTIVITY				
Number of driver workdays				6
Number of routes				10
Total vehicle travel time				14h.57m.
Total vehicle travel time without passengers				5h.10m.
Total vehicle waiting time				13h.20m.
Total handling time				7h.40m.
STATISTICS	DPR	VPR	PPR	TVR
N	6	6	6	6
MEAN	1.79	4.00	5.64	1.00
MEDIAN	1.92	3.99	5.55	0.97
MINIMUM	0.30	3.27	4.53	0.91
MAXIMUM	3.87	4.67	6.89	1.15
1st QUARTILE	0.45	3.50	4.81	0.92
3rd QUARTILE	2.62	4.59	6.55	1.08
STANDARD DEVIATION	1.30	0.55	0.90	0.09

7. CONCLUSION

The construction of routes and schedules for several vehicles to serve hundreds of requests is a highly complex task when handled manually. This task is destined to become more and more complex as the clientèle expands. Given the complexity of the task and the high costs this engenders, the use of computer tools becomes essential. The solutions produced by our software are superior both in terms of the quality of service provided and in terms of vehicle productivity. In addition, many questions can be raised about the organization of this type of service. For example, we might question the composition of the vehicle fleet, the rules concerning reservations and cancellations and the procedures for confirming requests with clients. To answer these questions, a computer tool such as ours is necessary so that various operating scenarios may be simulated and the impact of different policies on the quality of service and productivity may be analyzed.

Presently, the major Canadian cities are at the stage of implementing management systems. The following step which is already being prepared for some of them is the integration within these management systems of programs to assist in the construction of routes and schedules.

The expertise developed during this project has had and will continue to have a beneficial effect on research in this field. We cite here some of the work generated following directly from this project.

The team Desrosiers, Dumas and Soumis is working on an adaptation of this algorithm to make it suitable for the reoptimization of vehicle routes and schedules for the transportation of the handicapped [5]. In order to respond to certain questions concerning the organization of transportation for the handicapped, the software developed in this project along with Toronto test problem data are being used in a study being undertaken by the Centre de recherche sur les transports of the Université de Montréal. The objective of this study is to analyze the impact of various operating scenarios on the construction and quality of routes [6].

We are well aware that automatically generated routes and schedules are rarely acceptable in their entirety to users because of various special constraints. We are therefore currently developing an interactive graphical package which will allow the user to visualize the routes and schedules and make manual corrections. This program is similar in conception to one previously developed for school transportation [7], although the situation is more complexe here because of the cecessity of visualizing on the screen the notion of time, which is always present in the problem of the transportation of the handicapped.

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